\W

BROADCAST CONTROL OF AIR TRAFFIC

2D QUARTERLY PROGRESS REPORT

NASW 2247

G. LITCHFORD
LITCHFORD SYSTEMS
DECEMBER 1971

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

SIMPLIFIED PILOT USAGE OF LF/VLF
SYSTEM OF NAVIGATION USING
"BROADCAST CONTROL" CONCEPTS

INTRODUCTION

Some momentum toward the use of LF/VLF techniques for aircraft navigation and traffic control is now evident. The recent (Nov. 9-11, 1971) Omega Conference (Reference 9) held by the Institute of Navigation (ION) in Washington, D.C., saw some 400 experts assemble and present papers on nearly every aspect of the Omega system. Three significant LF/VLF aviation possibilities exist: (1) use of Worldwide (WW) Omega; (2) use of an "Omega-like" system optimized for aviation use in the 48 contiguous states; (3) a "mix" use of (a) WW Omega and VOR, (b) U.S. Omega and VOR, and (c) U.S./WW Omega. Fortunately at very low cost these possibilities can all be tested with the current plans for WW Omega.

WW Omega is an 8-station complex that serves the air and surface regions of the entire world with at least three Lines Of Position (LOP's) everywhere. By using three frequencies the diurnal and other LOP shifts are greatly reduced by heterodyne methods, such as "Composite" Omega, extensively tested by J. A. Pierce of Harvard University. The technical papers from the conference and hundreds of previous publications suggest that the Low Frequency navigation has a great deal to offer aviation users.

It was reported that Russia has introduced an LF/navigation system of its own operating near the 10.2 and 13.6 kHz frequencies of Omega (Reference 1). A previous study (References 2 and 3) has suggested a similar move by the United States of America wherein the 48 contiguous states would be served by a 4-station net (or "chain"), giving several improvements over WW Omega--primarily cost reductions and freedom of international political changes since only 2 of the 8 Omega stations are on U.S. soil (North Dakota and Hawaii). However, it was reported by the U.S. Coast Guard (and other national authorities) that Omega would be fully operational with greatly improved, new, high-powered stations by early in 1974. The detailed pictures showing the construction status of the Japanese station added considerable credibility to this schedule.

Because of other trends (reference 12), general aviation may be the first large aviation user of WW Omega signals. The possibility of a supplemental VLF system for the United States does not imply that WW Omega will not be adequate, but that for many reasons this useful experience will undoubtedly lead to a U.S. national LF/VLF system such as the Russian reports indicate became desirable to cover several unequipped parts of the nation and to optimize signal levels, etc. The Canadians are also very interested in such ideas as only the most southerly portion of Canada has VORTAC airways. The majority of Canadian airspace is too thinly populated with air traffic to warrant any expansion. Because VORTAC is too costly for large regions of coverage, such as, say, an area 2,000 by 3,000 miles, aviation's hope must rest with these techniques of LF/VLF navigation and traffic control.

WORLDWIDE VS LOCALIZED OMEGA

Currently so much attention is focused on the enthusiasm for the worldwide use of Omega as the first radio and only navigation system to be readily available anywhere. Often the problems associated with this global use are carried to general aviation, and many suggest Omega receiving techniques and navigation techniques will be too complicated for the general aviation pilot, adding too much workload, control settings, etc. This need not be so with good design of a low-cost general aviation receiver. Since the pilot workload using VLF navigation applied to general aviation is of concern to many private and government authorities, it needs some examination.

We will start with the simplest use, only in the US/NAS system, and only use by general aviation. Here we deal primarily with the single engine, light plane owner, who operates over short distances and into remote fields; his aircraft is not pressurized so it is operated below, say, about 10,000 feet. The only fair measure of pilot workload to be made is by the comparison of LF/VLF usage with the usage of existing VORTAC system.

The goal is to provide the same equivalence of data to the pilot. With VORTAC we deal with many separate systems that have characteristic VHF limitations. For example, at critical low altitudes of interest to general aviation, the line-of-sight coverage of VORTAC is about 10 to 50 N. miles. This service area depends upon intervening terrain, which in many instances limits the low altitude coverage to considerably less. With trends of "keep them high" (Reference 10) in FAA terminal areas, the airlines tend to stay about 4,000 to 5,000 feet, leaving general aviation between about 1,000 and 3,000 feet--a current trend toward vertical segregation.

It seems equitable to both systems if we now compare the use of Omega or LF/VLF navigation to VORTAC on the basis of, say, a 100 by 100 mile square. A fair assessment can then be made of a general aviation pilot's workload, and other problems that may be related.

To begin with, both systems are "differential" in their use by the general aviation pilot operating the light single aircraft.

"Differential" means that he must tune to locally referenced navigational signals to obtain enough information to use the coordinates. If it is a case of VOR-only usage, the pilot must know approximately where he is located first in order to tune to the right VHF channel as most of the nation's VOR signals will be beyond his immediate line-of-sight. Once he tunes the VOR station "in" by assuming its approximate location in its selection using the radio frequency as the "station-identifier," he must assure himself that the channel selector or his operation of the dials did not select the wrong channel or the wrong VOR station. Occasionally channels may even be shifted by the FAA. This assurance of the local reference is accomplished by listening to the audio output of the VOR (be it a voice or Morse code). The identity of the VOR is then established, and the chart establishes the expected VOR differential signal.

Next our subject pilot (using the VOR-only system) must select or measure the radial he is actually on by turning the course selector knob. When the course deviation indicator (CDI) needle passes through zero on the analog, right/left deviation indicator, the course (or its reciprocal) is then evident. A "to-from" indication resolving direct or reciprocal bearings must be observed by the pilot before he can bracket and fly the radial. He may desire another radial rather than the one he is on, so must select this also.

Not knowing his exact distance from the VOR (without DME), he must now obtain some "cross-fixing" data, such as tuning to another VOR station to obtain an approximation of his location on the VOR-radial-LOP emanating from the ground position of the selected VOR station. With these several manual operations by the pilot while in flight, and while continuously referencing the OBI and CDI to a chart, it is then possible to fly along the radial to or from the station, toward some destination. Destinations are seldom VOR stations, so varying the selected radial when passing over the station is commonplace.

If the destination is near the signal limits of the first VOR, it will then be necessary to select another VOR station going through most of the same procedures (cockpit workload) as noted above. To proceed requires continuous selection of various factors as the VOR LOP's are traversed. It is likely that the two radials from the two adjacent VOR stations that would align themselves to make a continuous path indication (CDI at zero) will not align smoothly with one another, since VOR errors of 3 to 4 degrees are common. If one station emits its radial in error in one direction (+ plus 3°) and the other station has an error in the opposite direction (- minus 3°), then the indicated spatial track could shift by as much as 3 to 4 miles (say 40 miles from one station and 30 miles from the other). This is disconcerting to the pilot and emphasizes the discontinuous nature of VOR signals and the difficulty of using them in a single-pilot, single-engine aircraft where all the cockpit workload is concentrated on a single person rather than shared as in most airline operations.

With no basic master plan for VOR stations that is easily remembered by a pilot and no plan that relates either to adjacent frequencies or adjacent station locations, the pilot must be continuously referring to VOR charts to proceed. This is to note that the many hundreds of VOR stations are <u>not</u> laid out or aligned on any basic "grid-plan," as, for example, a rectangular grid plan with a VOR at each crossing of the grid.

Nor are the radio channels arranged so that consecutive stations have consecutive frequencies. Random processes seem to have been employed in the configuration of the nation's VOR system. Consequently, the pilot must fly a series of VOR legs (or radials) that wander in the general direction of his destination but may vary in heading by tens of degrees from one VOR radial to the next VOR radial because of the local terrain, airway restrictions, etc., but mostly because of the random siting of VOR stations and the inability of the pilot to use some simple mental processes or rules for preventing this high workload. VOR and VORTAC are most complex systems to use and create many pilot restraints. The VOR or VORTAC cockpit workload is unnecessarily high.

The addition of DME to VOR helps in some respects but complicates the combined use in other respects, since the DME signals must also be identified, and the pilot must assure himself that the DME is from the same origin as the VOR. Fortunately, "cross-channelization" tie the two together. DME coverage is not always consistent with VOR coverage, depending upon the location, terrain, specific airborne units, VHF and L-band aircraft antenna placement, etc. Vertical lobes of the ground station are the largest contributor to the lack of coincident VOR-DME coverage. L-band has <u>10 times</u> as many deep nulls as VOR in a given vertical angle, etc. Thus, when <u>both</u> are essential, the coverage may not overlap. If now the costly Area Nav (R-Nav) computer is added, we further burden the pilot with all the foregoing workload of VOR-DME usage, but he now must determine and set in his "way-points" (usually two of them) and fly an "RNAV" airway rather than a radial airway. The advantage of R-NAV is that at least the origin-destination of the flight plan can be inserted. Such a flight might utilize, say, 3 to 4 VOR radials in 3 to 4 different directions to approximate it, but can now be approximated with a straight line eliminating the "dog-legs" created by VOR-only type of track flying. The pilot must, however, continue to change stations and waypoints, since each VOR creates a new set of waypoints that must be set in even though the spatial track itself is straight. Thus, less distance is flown, and better ATC procedures accrue, but R-NAV-VORTAC workload is still high for our single pilot, general aviation aircraft.

Moreover, the line-of-sight VHF-UHF coverage may now suffer at lower altitudes since the airway is not to and over the station. Say the R-NAV track is 30 miles to the side of the station (closest tangency is 30 miles), this places the aircraft at the maximum line-of-sight distance from the VORTAC station sooner than if only a radial were flown. Consequently, more station selections, station identifications, more setting of waypoints is added workoad. VORTAC - R-NAV, although adding some ATC and direct routing advantages, does add considerable workload to the single pilot flying a light aircraft.

COMPARING VORTAC AND VLF/LF PILOT WORKLOAD

With the LF navigational coordinates of an "Omega-like" system, there is first no radio channel selection required since the entire nations coordinates are only a single permanent setting for carrier frequencies. All three LF frequencies are used continuously and have equal coverage throughout the United States without vertical lobing or "cones of silence." The LF airway charts must still be referred to, just as in the VOR case, and the pilot must initially have an approximate idea of where he is (within about 72 NM) to set in other data.

The availability of this location is more likely in the case of LF than VOR since even on the surface the pilot can obtain a positional measurement on VLF, something usually impossible with VOR. The VOR signal, if from an off airport station, is too weak, or if from a VOR on the airport, the signal may be contaminated by hangar reflections. LF coordinates on a runway are as useful to the pilot as at 2,000 feet above the runway, there usually being little change in signal characteristic of VLF navigation. Next, the local "differential" setting is obtained with the same voice transmission that the pilot must make to obtain the local barometric pressure setting. Barometric data is essential to <u>either VOR or VLF</u> navigation during IFR flight, so the "differential-Omega" data is added to an existing network of data transmission to the pilot. This replaces perhaps the workload of station identity. The pilot may forgo the differential VLF data as he can achieve the same results or "zeroing" out diurnal effects while on the ground prior to takeoff.

The oblique-parallel nature of the Omega coordinates should provide the greatest step toward simplification of pilot workload. The pilot can easily envision his current position in VLF coordinates because the mental effort is much less. Also more easily detected in Omega coordinates is the position of his destination, and how he can get there. Contiguous parallel lines are much simpler than radials from random points. Essentially, parallelograms or rectangles are much easier "graphics" to envision and to manipulate by the pilot than randomly located spherical coordinate systems of VORTAC.

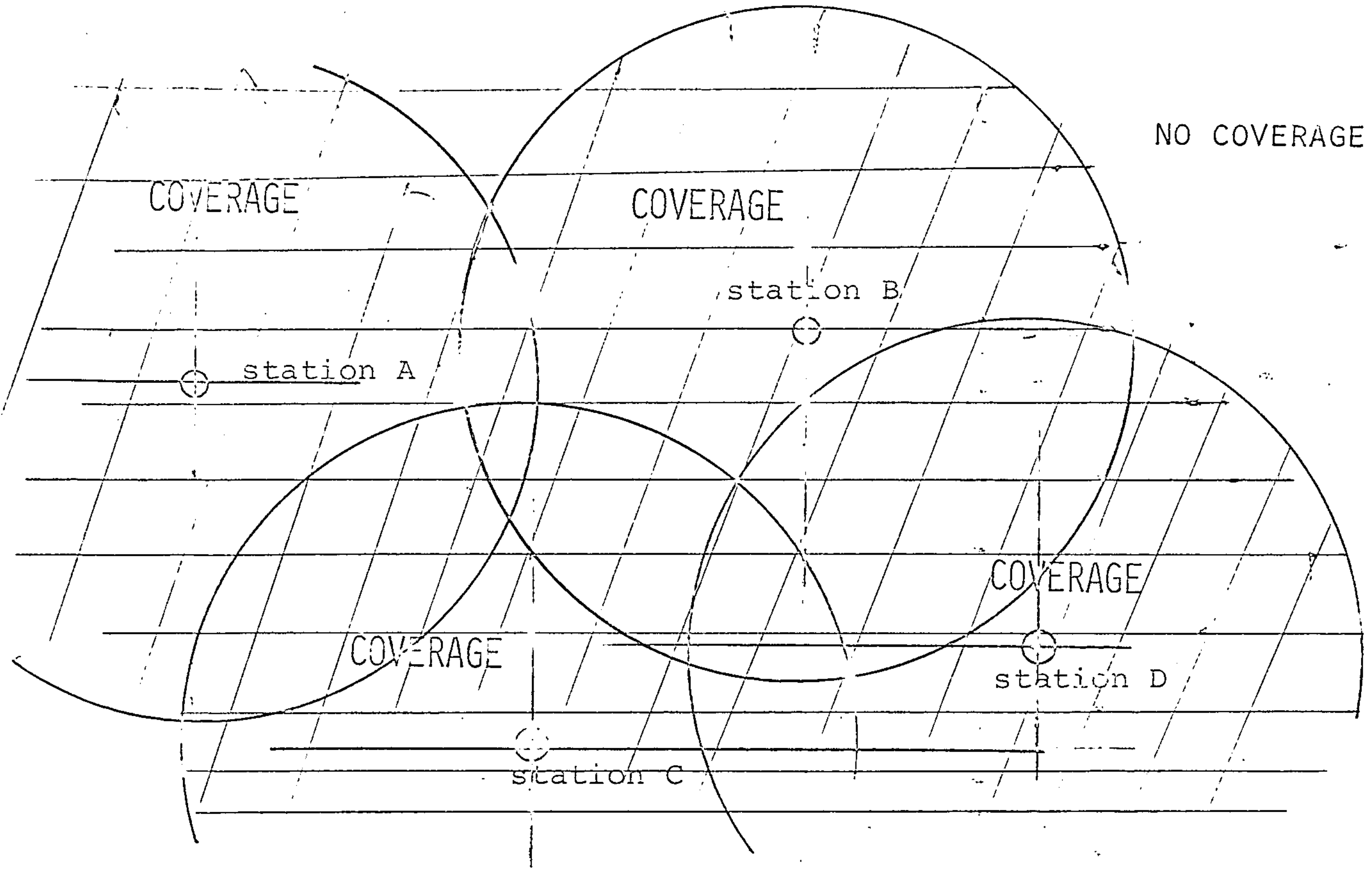
Thus, the pilot now selects his coordinate positions since he has in Omega, <u>by reception only</u>, the equivalence of both VOR-DME.

That is to say, he has a full set of crossing LOP's everywhere, with the single selection of the Omega channel for the entire nation--not 1,000 stations with 1,000 locations and 1,000 frequency allocations.

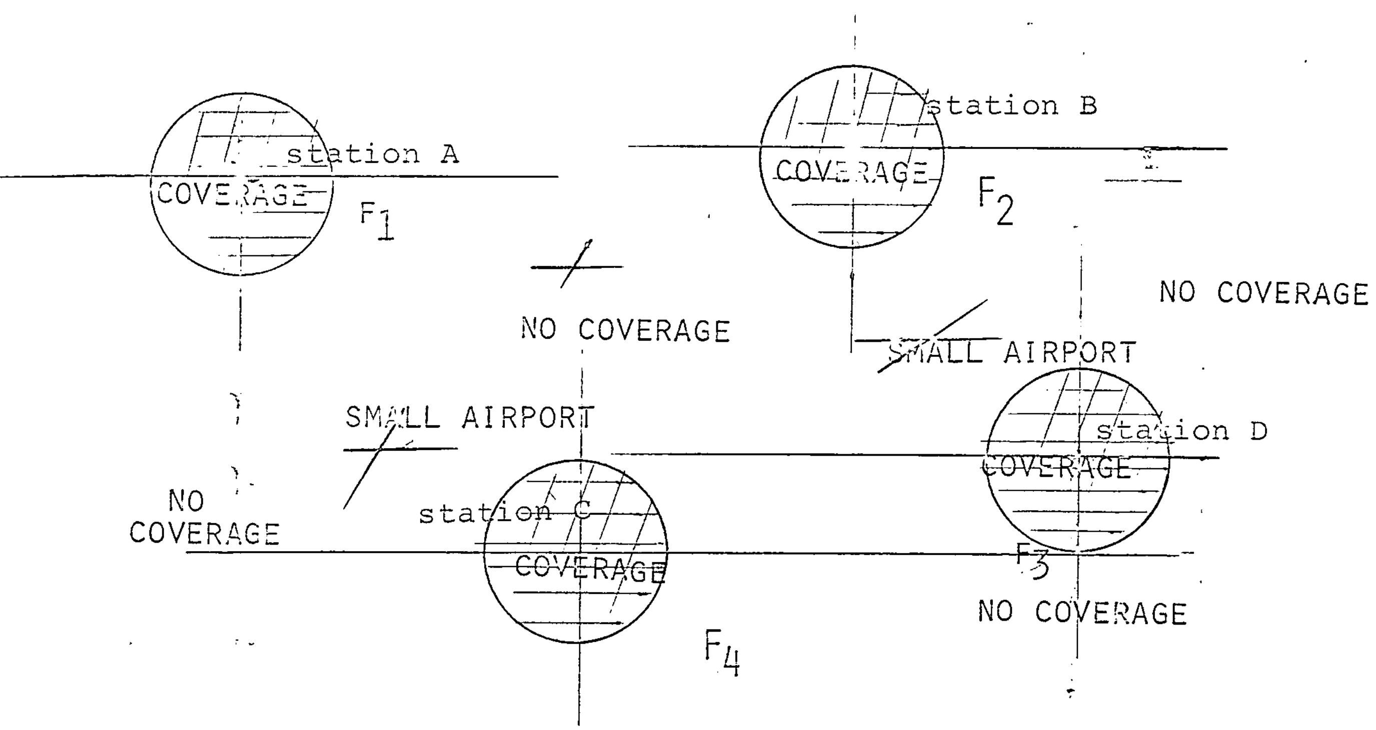
The differential input of Omega may simply come by the pilot's reception of Omega while on the ground, and his insertion of the destination coordinates; or from several local differential signal sources while in flight. ATC may also provide this data since the controller's view of the SSR target and its identity can be conveyed in Omega coordinates to a pilot. Such an input is good for about an hour. Several self-correcting differential techniques will probably be used by the pilots, including voice from VOR sites and the use of VOR and Omega, one checking or extending the other. The differential data is in terms of one LOP (say an E-W one), and the other LOP (the second LOP) is a N-S one. He notes the two LOP's which cross at his destination. By inserting these destination LOP's, the pilot can takeoff and fly on a straight line to this new location.

If the FAA has specified Omega airways or lanes, he can follow them directly. They need not be "raw" Omega lanes since neither of the two crossing LOP's may go in the desired direction. The computation of rectilinear or "oblique-parallel" LOP's is the simplest of navigational computation.

Importantly, there is no altitude correction needed for the use of VLF navigation. Individual station elevation is of no consequence as it is in VORTAC R-NAV. The latter difficulty of VORTAC can be envisioned if a station is, for example, at sea level and the pilot flies an off-set airway of about 2 miles tangency at 10,000 feet. The actual slant range at the point of tangency is about 1.4 times



VOR HIGH ALTITUDE COVERAGE OF 4 STATIONS (A-D)



VERY LOW ALTITUDE COVERAGE OF SAME VOR STATIONS

AT SAY 100 FT TO ASSURE A SOLID 400FT SIGNAL FOR

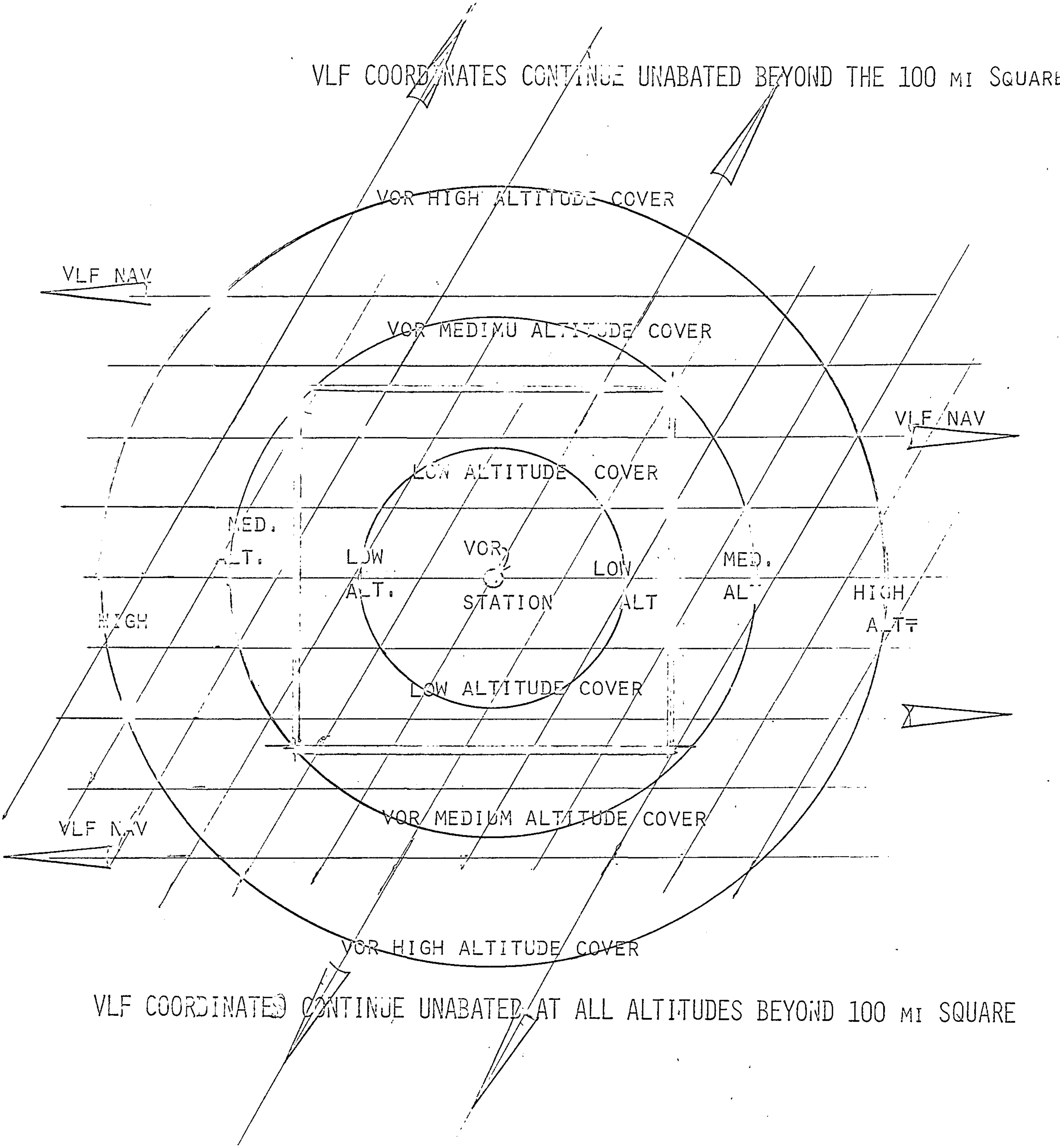
A 400- 1 or a "300-3/4" DECISION ALTITUDE

FIG 1 VARIATION IN VOR COVERAGE FOR APPROACH the desired off-set tangency distance, causing the aircraft to fly a curved track, curving in and then away from the station near the point of tangency. Similar problems exist between adjacent VOR sites particularly where widely differing elevations exist and high altitude flight is desired. The spherical coordinates of the two VORTAC stations must be off-set by the three elevation values: (1) aircraft, (2) VOR-A, and (3) VOR-B.

LANE AMBIGUITIES

The complaints about lane ambiguities are always raised by the critics of Omega. With the use of the two VLF frequencies, the ambiguities are about 24 miles apart (10.2 and 13.6 kHz create a 3.4 kHz heterodyne). If the third frequency (11.33 kHz) is used, the ambiguity is reduced to 72 miles, yet with little additional cost. A common multiplier frequency (408 kHz) exists for all three tones permitting simple data processing. The fact is that lane ambiguity of Omega is a problem of equal importance to the LOP ambiguities ("to-from") of VOR; they are quite similar in operational concept, particularly when 3 or more consecutive VOR's are considered. Neither LF nor VOR ambiguity problems are a serious operational limitation. Certainly no one avoids the use of VOR because of the 3 to 5 ambiguities that may be encountered in flying a track that connects a series of radials of VOR stations. Furthermore, the contiguous nature of Omega does not allow a lane to be lost--something never experienced by a VOR-trained pilot, who is accustomed to loss of VOR behind mountains and beyond line of sight.

Recall that we are discussing the slow, light, general aviation usage first. We are not discussing or analyzing pilot work-load of a 600-knot aircraft, flying on 2,000 to 5,000 mile trips where the speed and other matters call for a much more sophisticated Omega receiver display and pilot controls than we are reviewing here. Such a study should be conducted, however, its results are more obvious and its impact on ATC trends less. The successful solution to general aviation problems will tend to pace such developments as LF/VLF rather than airline usage, even though the airlines may benefit equally because of their own use of LF/VLF techniques or because the "dispersion" of air traffic routings reduces the traffic densities on routings (say to jetports) of greatest interest to the airlines. VORTAC has been installed mostly for the solution of the latter problem, while general aviation requires an equivalent low altitude service to thousands of remote airports away from or below jetport terminal traffic. Remember, we are making a one to one comparison of Omega and VOR pilot usage within only a 100 X 100 mile square, as in Figure 2. Of course, the ease of transition to adjacent 100 X 100 mile squares of airspace is equally significant. Even though we use "building blocks" of 100 mile squares in each case, this is done so that the VOR is given equal treatment on a station-by-station basis with Omega or VLF type systems. All the coverage at low altitudes for general aviation that is expected from VOR under favorable siting conditions is utilized. Probably in some locations, a 75-mile square at an altitude of 1,500 feet is more realistic, reducing the low altitude area by almost 50 percent for VOR. At a diagonal on the 75-mile square VOR the aircraft would still be about 50 miles from the station (see Figure 2).



A ONE TO ONE COMPARISON OF VOR AND VLF/NAV IN A
AREA 100 x 100 MILES
FIG 2

INFLIGHT WORKLOAD FOR A SINGLE
GENERAL AVIATION PILOT USING
DIFFERENTIAL OMEGA OR VOR

PILOT FUNCTION	VOR(or VORTAC)SYSTEM	LF/VLF"OMEGA-LIKE"SYSTEM
1.*Radio Channel Selection	(a)Look up in Chart (b)Turn Knob or Digit Selector	None - 3 fixed channels for all of U.S.
2.*Station Identity	Audio Monitor by Pilot to Assure Correct VOR	None Required as No Erroneous Stations Exist
3.Ambiguity Resolution	Observe "To-From" Indicator	Observe 72-mile Ambiguity Indicator
4.Course Line Selection	Set OBI Selector for each One	Set LOP Selector
5.*"Fixing"on Course Line to Obtain Position	Must add DME or Retune to Another Adjacent VOR and then back to 1st VOR, Creating High Workload	Receiver Continuously Obtains 2 or more Crossings of LOP's Automatically. Low Workload
6.*Course Deviation Flight Following	R-L Meter with 20 to 1 Variation in Sensitivity. High Load on Pilot	R-L Meter with Constant Sensitivity. Thus, Low Pilot Load
7.*Adjacent 100X100 Mile Areas	Must Retune and Repeat 6 Steps above for Each Area Adding High Workload on Flights Over 100 Miles	Contiguous Coverage, No Retuning. Low Workload
8.Way-Point Selection for "Area-Nav", Parallel Airway,etc.	Set Digit Wheel for Each Way-point and Add Costly 3rd Unit to a VOR & DME which is an R-NAV Computer. Equal Workload	Set Digit Wheel Receiver-Only Creates Simple Coordinates, Voiding Costly R-Θ Computer and DME. Equal Workload
9.*Pilot Assurance Prior to Takeoff	Can Tune to "VOR-Test" Signal into Few Large Airports, Otherwise None About 90% of Time	Full Operational Check While on Runway of at least 2 LOP's Zero Set Indicator to Actual Position
10.*Altitude Effects	a.Curved Course Near Station in R-NAV b.Vertical Nulls in VOR c.Vertical Nulls in DME d.Cone of Silence e.Lack of Useful Signal at Low Altitudes below 700 Feet or Behind Mountains	NONE. Works with Nearly Vertical LOP Measurements from Airport Surface to Over 60,000 Feet
11.Atmospherics	Minimum	More susceptible but can be "Engineered" at Low Cost Out of System Usage with Modern Digital Circuitry

* VLF (Omega's) Cockpit Workload Appears Less Than VOR or VORTAC.

COLLISION AVOIDANCE SYSTEMS AND VLF NAVIGATION COORDINATES

The recent investigations of several collision avoidance systems (CAS) (References 4 and 5) by the Congress of the United States emphasizes the confusion that exists on this subject. From some viewpoints there is no such thing as a true collision avoidance system. CAS is probably a misnomer. This popular term emphasizes a desire to avoid collisions but as a technical title of a system is poorly conceived. We will shortly point out that pilot track following of a universal navigation system superior to VORTAC is one of the best means to assure air-to-air separation. More importantly, assurance of air separation from ground obstacles, such as mountains, power lines, irregular terrain, buildings, etc., will reduce fatalities more than air-to-air techniques. Both are needed to protect each aircraft from collisions with the surface objects or other aircraft. VLF can be used to aid in both cases because of its universal, simple coordinates and low altitude signal coverage. The illusion of some breakthrough solving the air collision problem is prompted by some of the admittedly spectacular mid-air collisions occurring during the past 10 to 20 years or so, since the famous Grand Canyon case. Newspaper and magazine pictures of a broken DC-8 lying in the streets of Brooklyn, the result of a mid-air collision with 100% fatalities, will not soon be forgotten.

Scientific and engineering attacks on preventive means for vehicles in motion to avoid collisions has long been sought in both marine and air navigation.

The United States' preoccupation with several sophisticated "CAS" equipments is reviewed by a European expert in a recent journal (Reference 6). His views may be more objective as a controversy over techniques has arisen in the United States (References 4 and 11). This authority notes the "scientifically frustrating" situation in aviation that has developed, and he relates them to similar frustrations in the marine world. The following summarizes from this informative paper on air-to-air collisions:

A. No matter how early the threat (air-to-air) is detected, the angle and range data is so limited it is impossible for the pilot to make a successful contribution to avoiding a collision by using information derived from range, relative velocity, and bearing angle.

B. Using range and elevation (and their first derivatives) for a vertical maneuver within the existing ATC limits for vertical separation requires altimeter accuracies well outside the FAA standards (see DOT ATCAC study on accuracies of barometric altimeters, reference 7).

Three-sigma altimeter errors of 620 feet are estimated for general aviation and nearly 300 feet for air transports (Reference 7). Unless a national "in-flight"altimeter calibrating system is developed, assuring no more than about 100-foot errors in terminal area operation, any CAS system requiring less than the 1,000-foot vertical separation must first solve the altimeter error problem. Most such CAS systems "command" the pilot to execute a rapid vertical change of about 200 feet, a value much smaller than DOT/FAA reported errors of altimeters. All altimeters, particularly general aviation, must be considered. For example, two aircraft actually separated (vertically) by 200 feet (within FAA tolerances) might collide as a result of the 200-foot vertical height change commanded by the CAS indicator. In any system engineering involving possible fatalities, the measurement accuracy should <u>exceed</u> the operationally desired results by five to ten times. This would suggest vertical maneuvers of about 1,000 feet would be commensurate with current altimeters, something completely unacceptable in our national airspace system where the 1,000-foot vertical separation has become standardized.

The following extracts, quoted directly from the author's paper, further clarify this view:

1 "For two aircraft, in straight line flight at constant speed, that are due to miss each other by a small distance m it can be shown that m is given, approximately, by either of the formulae:

$$m = (\ddot{r} r^3 V^{-2})^{1/2} \qquad (1)$$

or

$$m = \theta r^2 V^{-1} \qquad (2)$$

where r, V and θ are respectively the range, relative velocity and relative bearing of the two aircraft. The practical difficulties of basing a collision warning system on either equation are formidable. If M is 1,000 ft., V is 500 ft./sec. (300 knots) and r is 15,000 ft., then $\ddot{r}$ is 0·08 ft./sec.^{2} and θ is about 0·002 radians/sec. The sight line is therefore rotating just a little faster than the minute hand of a watch. Neither a human observer nor a radar scanner is likely to detect such a movement."

2. "...then unless our pilot can detect a sight line <u>rotation of about 1° per second it is impossible for him to</u> make a useful <u>contribution to avoiding a collision no matter how early the threat</u>

is detected."

3 "...time-frequency system which is based on collision avoidance by vertical manoeuvre in response to telemetered height data from the other aircraft. Broadly, the object is to make a last-minute manoeuvre to miss the threat by a vertical distance of the order of 200 ft., so that it is possible to argue that A.T.C. rules are not infringed by the manoeuvre. An attempt is made to guard against the worst-case situation (assumed to be a ½g turn by either aircraft or a rate climb/descent of 10,000 ft./min.). The logic measures relative range and height, and their first derivatives, for all equipped aircraft in line-of-sight, and computes for each the ratio of range to velocity, or 'Tau',..."

4 "Holt and Anderson[8] give some account of the underlying theory, but it must be cautioned that there is a shortage of experimental evidence to justify the numerical assumptions. In particular an altimeter could easily meet the present day FAA standards and fall well outside the limits assumed by Holt and Anderson."

5 "It can be argued that even a moderately effective collision avoidance device used in this way is well worth while; the question is whether the hazards due to avoidance manoeuvres in response to false alarms are themselves as dangerous as the situations being avoided. Since at a rough estimate there may well be 1,000 full-scale alarms per collision this possibility is far from remote.

"The fundamental difficulty is that in a crowded terminal area, where the collision risk is greatest, A.T.C. is planning quite intricate traffic patterns. Even the considerable complexity of the C.A.S. logic cannot begin to recognize these patterns and to make a sensible differentiation between 'safe' and 'unsafe' situations. A comparable expenditure on electronics to aid A.T.C. rather than to set up in rivalry might show much better returns."

There is a growing view that the pilot should maintain a track that avoids other aircraft based on a centralized plan affecting all traffic for some time span into the future, say, 30 to 45 minutes or even an hour. This is part of the concept of "Broadcast" of "Strategic" Air Traffic Control. Both VFR and IFR flights are directly or indirectly controlled. Uncontrolled flights, wherein the pilot flies any path he desires are rapidly becoming a thing of the past. A collision avoidance system will do little more than they have done in the marine world unless all traffic moves in some form of specified airspace. For example, nearly all ships have radars of one form or another, however, the marine collision rate has been so bad with radars operating that studies on "Radar-assisted" collisions have been undertaken. With much longer marine warning times, etc., there is yet to be found any universally accepted means of marine collision avoidance except by some form of central control, such as shore-based radar and Navaids.

If a uniformly spaced set of universally available coordinates exist, such as LF/VLF coordinates (like Omega), it is likely that the aviation collision avoidance problem would be solved by much simpler means than now proposed in independent CAS systems. The present <u>un</u>availability of this uniform, low-cost, universally available set of coordinates is probably the basic cause for air collisions. The so-called VFR "see and be seen" concepts of free flight by aircraft must become a thing of the past as aviation expands. Another analogy is roads and highways. Just as roads "organized" surface traffic movements from random cross-field tracks thousands of years ago, a similar "air track" to specific desired destinations at all altitudes must now be provided aviation. Simply put, two motorists approaching each other at high speed on a road cannot avoid each other based on their observations of the angle or range data (or their derivatives) as the values are too small to be useful in time to avoid an auto collision (as the reference above clearly states). The driver of an automobile knows from common traffic rules that he <u>must stay</u> on his lane and be centered on it, thus occupying only half of the road and, thus, he will avoid collisions with all the other oncoming vehicles.

Lane assignment and use by every participant, conforming to universal rules, requires a common means of forming tracks at low cost for all parties to comply. This is another facet of "Broadcast Control." Aviation must ultimately adopt this concept, but the concept requires a navigation and guidance system that will allow continuous "roads" to be specified by authorities in any direction, anywhere, and at any altitude before the concept can be adopted. Radar surveillance is not the entirety of ATC. Navigation coordinates must come forth that determine all ATC procedures. VORTAC with its many deficiencies of interrupted service, at low altitudes, high pilot workload, and poor "geometrics" consisting of a thousand randomly located, separate, spherical coordinate systems not related in any manner simply won't permit new concepts of Broadcast Control to evolve.

Thus, one view is that to avoid collisions between aircraft, we do not need a new independent CAS system that might result in "radar assisted" collisions, but to go to the heart of the problem and provide universal, simple lanes and assigned air tracks that assure positive separation under all conditions of VFR or IFR and avoiding the "see and be seen" concept (almost completely) in ATC rules.

<u>CONCEPTS OF "PROXIMITY CONTROL" OR AIR-TO-AIR SEPARATION TECHNIQUES</u>

The previous discussion is not to suggest that all problems are solved if independent tracks are provided in three dimensions. Just as in rear end and intersection collisions between automobiles, the <u>common track separation criteria</u> must also be established. That is to say, many aircraft will use a common track that may be contiguous (without frequency change) for short or long distances, even up to 3,000 miles across the nation. Such a grid of tracks exist everywhere. The problem identified here is that two aircraft on a common track at different velocities may close the spacings between each other so that separation criteria are violated, simply because the aircraft cannot see or measure this separation between themselves, or perhaps because centralized ground ATC is lacking for one of several reasons, technical or administrative. The centralized ground ATC, with the three billions of dollars of SSR investment, will not change substantially for at least 10 to 20 years. However, SSR (for ground surveillance and ATC) operating at a frequency of 1,000 MHz does suffer from coverage gaps. In dense traffic areas the SSR coverage is extensive, with about 700 stations in the United States alone (and perhaps ultimately that many in Europe).

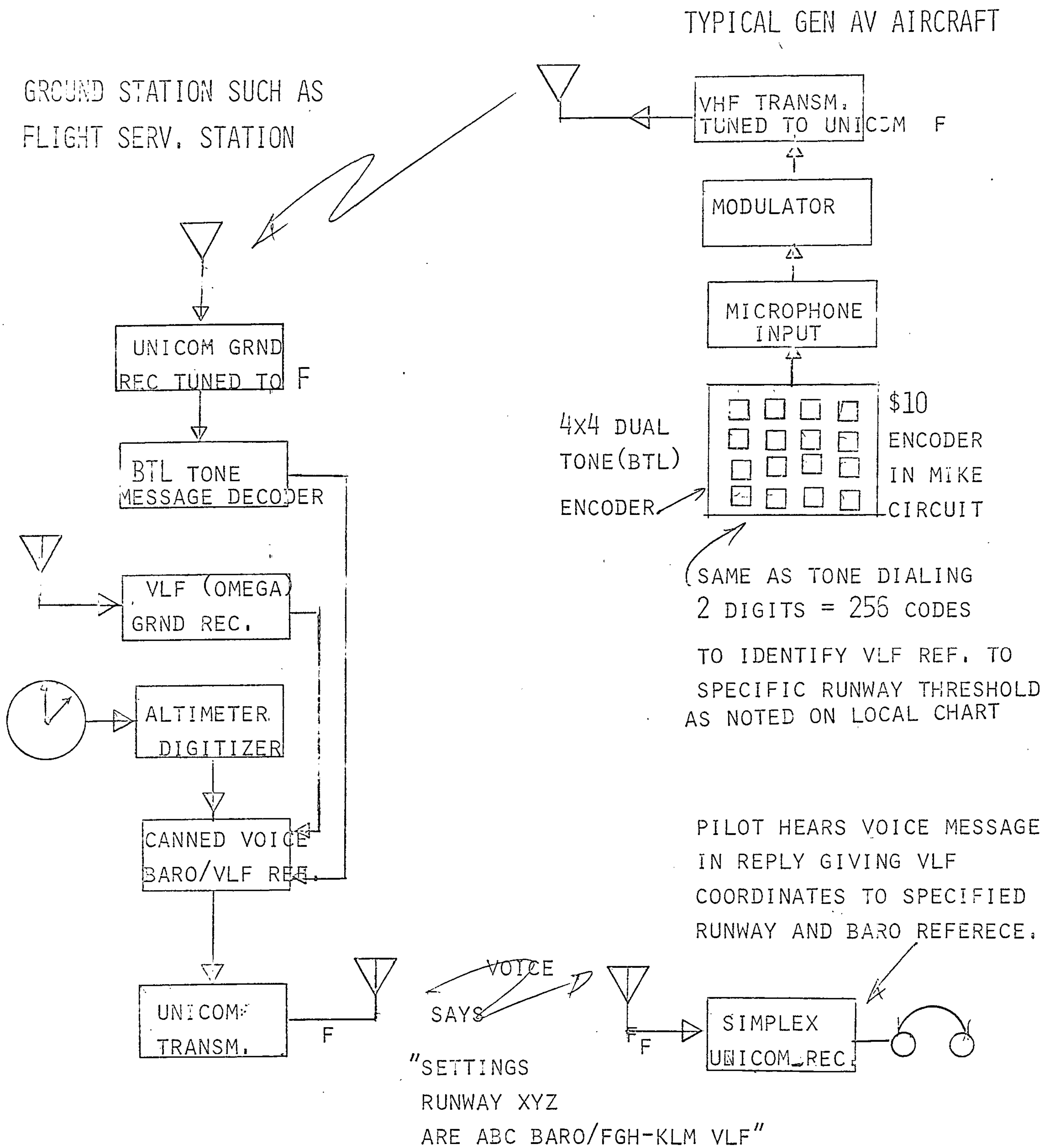
Thus, two pilots would observe the fact that each is proceeding according to new ATC rules on the same common track, by an air-to-air exchange of data. This air-to-air exchange would also establish the assigned altitude, range, and bearing of the aircraft. Bearing may be used by sophisticated aircraft to pass a slower aircraft on a common track, a concept of something quite different from collision avoidance (as previously described). Pilots will note parallel air tracks (just as in highways sometimes with up to 8 parallel lanes, 4 lanes in each direction). This concept of proximity control then shifts a major ATC load from the ground controller's responsibility to the pilot, where it is more commensurate with pilot responsibility. The pilot is present where the actual controls exist to affect these ATC functions of Proximity Control. The pilot can, without dozens of air-ground complications, follow a track and schedule with high tolerances and view traffic ahead and behind him on his common track. This "fore and aft" pilot-to-pilot control assures the overall requirement that the ATC separation criteria (say spacing is of 2 to 3 miles) is <u>not</u> violated. SSR will overview the separation but not control it.

Several existing systems or techniques will permit this air-to-air exchange, the most likely being the airborne SSR transponder, since (1) it already exists, (2) it sends out altitude and identity codes automatically and continuously, and (3) it can be readily received by other aircraft with the addition of a receiver and a simple processor. The aircraft using its SSR transponder can now send over 4,000 codes for ATC purposes. Such codes are now assured, but others are available or assignable without any change in the national standard for this three billion dollar system.

ATC EXTRAPOLATION OF SSR AND LF/VLF SIGNALS FOR ATC PURPOSES

It can be argued that at low altitudes, such as the 400-foot decision altitude (DA) of a non-precision approach, that ground ATC (SSR) surveillance cannot be assured across the nation. This is to say that LF/VLF, not being restricted by line-of-sight radio transmission, can now be used to create a three-dimensional approach track to any runway or strip in the nation. With differential LF/VLF data acquired simultaneously with barometric data, it is possible to obtain by existing communications simple "canned-voice" messages from a Unicom frequency with an identity acknowledgment to the requester. A simple technique is suggested in Figure 3 using standardized elements of our national telephone network. This low density, remote area general aviation concept could offer adequate service to general aviation at a cost level to meet their needs.

With the new concepts of ATC, where the airlines may stay above 4 to 5 thousand feet until near the terminal, general aviation



ADDITION OF $10 TONE ENCODER TO EXISTING AIRCRAFT VHF COMM UNITS PROVIDES SELECTIVE DIFFERENTIAL = OMEGA (VLF) DATA AND BAROMETRIC SETTINGS

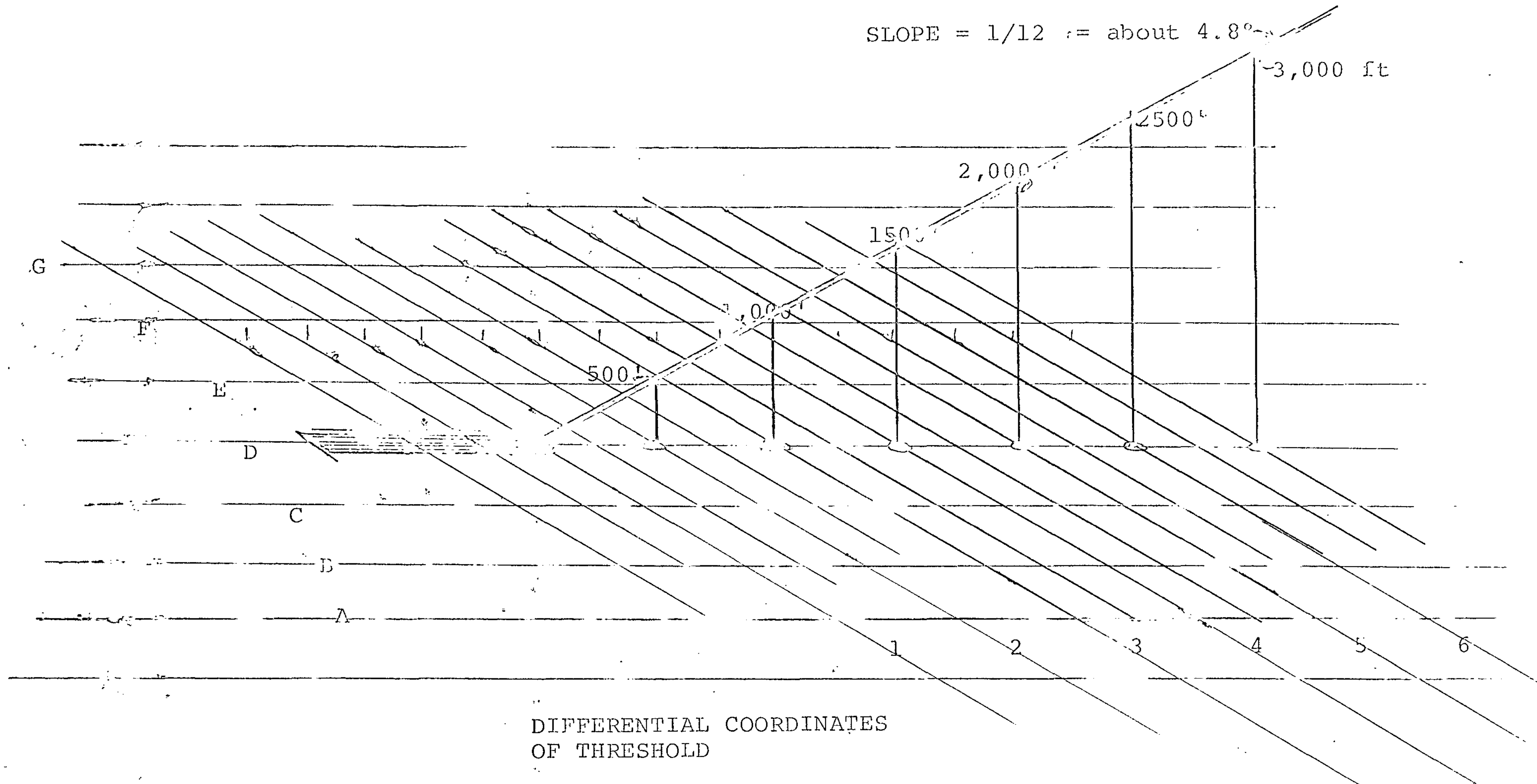
FIG 3

may use altitudes between the lower of these "keep them high" altitudes and the minimum altitudes typically of about 1,500 feet. Thus, we have some segregation of traffic. However, climb corridors must be crossed occasionally and some of these are as long as 35 miles, extending from the jetport to a height of about 14,000 feet. A pilot flying VFR must call ATC to cross these corridors. This type of operation and many others effectively require some form of SSR surveillance which is only available above about 1,500 feet on a national basis. Considerably less SSR coverage than this exists at, say, 400 feet. Typically, about 50 NM range to 200 NM range is possible with well sited SSR stations interrogating aircraft above 2,000 feet. Coverage decreases to about 20 NM at around 700 feet and about 20 NM at 300 feet. Although the above values are only approximated, varying in value according to topography and elevation of the SSR interrogator, from the viewpoint of general aviation the values are of great significance.

If, for example, a general aviation aircraft operating at 3,000 feet is being tracked (while it flies on an LF/VLF (R-NAV) airway) by SSR ground surveillance, and then starts to descend in altitude, going below the coverage of the national SSR network in that locality; the path, track and schedule can still be accurately extrapolated by ATC. Since both SSR and LF/VLF are in use prior to the time of descent, either can be used--VLF of course being preferable.

When the pilot is allowed, say, to cross an airway or corridor or to let down into a remote airstrip beyond SSR cover, the combined SSR and LF/VLF <u>tracks prior</u> to the loss of ATC centralized ground tracking are used by the controller to extrapolate the next section of the flight, that follows an agreed-upon track, altitude and time profile. Using this procedure the pilot is assured that the R-NAV data is registered by and with the independent measurements of the SSR; the pilot is assured that track speed, wind, heading, etc., have been computed prior to leaving SSR cover and entering extrapolated ATC procedures on LF/VLF coverage. Since the VLF coverage may permit a non-precision approach into a remote airport without a control tower, the SSR ATC data can be used to assure the pilot that the extrapolated low altitude track is correctly aligned with runway centerline (angle and displacement) and that the altitude descent schedule will be executed with minimum risk. This is the "differential Omega" concept introduced as an integral part of ATC, so that all errors are independently checked prior to exposure to obstructions on descent. Non-conflicting airspace, available for another flight, is reduced in this manner.

Since the 3-dimensional R-NAV position is shown to both pilot and controller alike (video-map displays for the controller and R-NAV cockpit displays for the pilot), the two systems can be brought into registry. Since LF/VLF is a contiguous system of coordinates, it can span many SSR systems connecting any two SSR surveillance systems together where overlapping coverage is not possible, by a simple pilot dead-reckoning when between the two coverage diagrams. It is not always possible, economically or technically, to achieve SSR surveillance, say, to altitudes below about 500 feet surrounding remote airports. Thus, traffic at about this altitude or lower will go into and out of SSR coverage as seen in Figure 4. If the aircraft were at higher altitudes, the SSR cover is greatly improved, but the general aviation aircraft then may be forced to "mix" with the higher



IF SPACING OF LOP 1-6 IS 6 NM, EACH IS SPACED 1NM

PROGRAM OF ALTITUDES FOR NON PRECISION APPROACH TO A RUNWAY USING AN "OMEGA LIKE" VLF NAVIGATION SYSTEM.

FIG 4

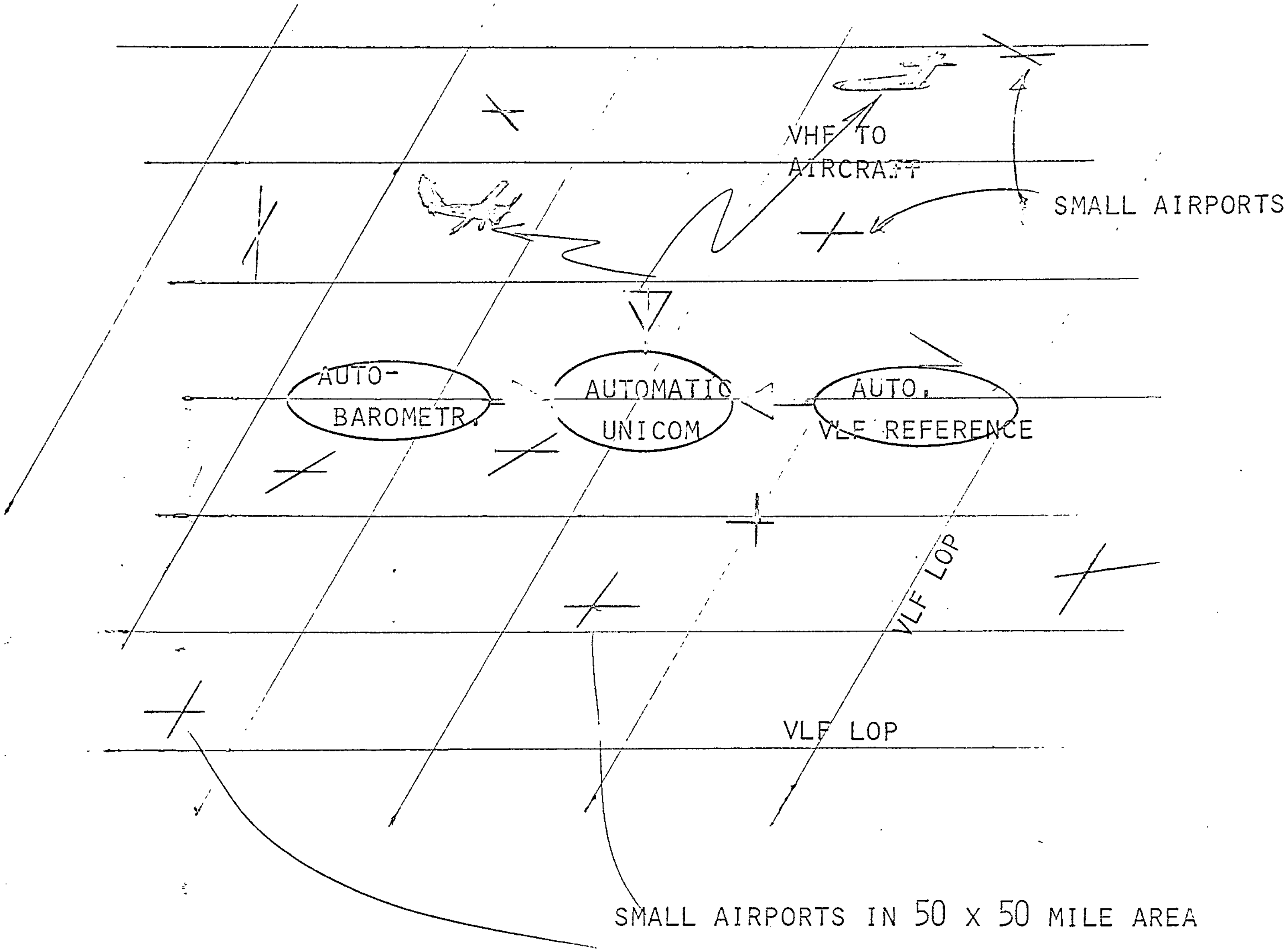
speed jets and be possibly affected by wake turbulence, delays, collision threats, etc. VORTAC coverage is not continuous nor is SSR coverage continuous, so that the two do not complement each other very well for this concept of ATC extrapolation. In fact, the low altitude coverage of SSR and VORTAC are not even coincident, since the two polar coordinate systems (both line-of-sight limited) are not sited at common locations (except in a few rare instances). However, with contiguous coverage at all altitudes of VLF/LF systems, such as Omega, this coordinating or integrating together the coverages of adjacent SSR sites is readily possible and should be a great asset to ATC.

A controller, knowing the aircraft is going into a location beyond SSR range, can extrapolate and "hand over" the traffic to another radar and controller while the pilot continues on the same grid uninterrupted since the same grid overlays both SSR sites and all other SSR sites. The controller can also, in emergency conditions, give the pilot his LF/VLF coordinates by correlating the SSR data with LF/VLF coordinate data, something easily done with the hundreds of digital processors in operation that convert R-Θ SSR data to rectilinear data, since the overlay will permit this. That is to say, the differential corrections of LF/VLF can be provided by the controller and his SSR processor since the two systems' accuracy is about equal on average on a 100 X 100 mile basis. Thus, pilot use of LF/VLF systems for Broadcast Control is differentially corrected routinely (once an hour) by the total system, minimizing the need for localized corrections. For example, the pilot might switch to one of the 4,000 identity codes reserved for transponders and obtain his differential Omega data automatically addressed to him in a "canned voice" communication, similar to Figure 3.

"VFR-AIRWAYS" USING LF/VLF

Some proposals for introducing the LF/VLF system concepts of ATC are based on the "controlled" airspace being established by VORTAC coordinates and the VFR's airways for general aviation being LF/VLF systems. The latter create airways parallel to but separated from the controlled airways (Reference 9). This concept effectively suggests that simple "see and be seen," VFR navigation is becoming a thing of the past. This concept, suggested as a possibility by the FAA (reference 9) offers a first evolutionary step that may be acceptable to many private and government authorities, so that a real test of VLF/LF can be realized. In this manner, general aviation would not be required to follow the dense airline airways. The user of the smaller aircraft could be assured of ATC protected, non-conflicting flight paths with respect to the airlines, and the airlines can be assured of ATC protected, non-conflicting flights with respect to small, single-pilot, single-engine aircraft. Most importantly, this concept provides signal coverage and ATC service otherwise not available to general aviation, encourages "dispersion" of traffic rather than "convergence" of traffic, and typifies the principles of "Broadcast Control." Figure 4a illustrates this. This VFR airway plan could be a three-dimensional concept where the two LOP's, horizontal dimensions are created as well as vertical dimensions. The simplicity of pilot VLF usage over VOR usage and the contiguous low altitude cover of VLF, previously described, suggests that with perhaps a 10 percent increase in instructional times, a private pilot could be capable of at least avoiding specified areas, and perhaps could even fly a "VFR-airway" at the time he receives his pilot's license.

VLF COORDINATES IN AREA ABOUT 50 X 50 MILES



AUTOMATIC UNICOM PROVIDES BAROMETRIC AND VLF REFERENCE DATA TO EACH AIRPORT IN LOCAL AREA SO THAT ONE VLF GROUND RECEIVER SERVES AS MANY AS 10 AIRPORTS IN AREA

AREA USE OF DIFFERENTIAL OMEGA REFERENCE DATA GREATLY REDUCES COST OF VLF USEAGE

FIG 4 A

NOISE ABATEMENT USE OF LF/VLF NAVIGATION (VSTOL AND GENERAL AVIATION)

As noted previously, the average (area-wide) accuracy of an "Omega-like" VLF system is superior to VORTAC and with differential corrections can be provided the pilot approaches that are on runway centerline, avoiding approaches with up to 30 degrees of divergence and avoiding positional errors from remote off-airport VORTAC's. Or conversely, one can argue VLF will avoid the addition of about one to two thousand more VOR and VORTAC's to give a 400-1 NM service to all of the thousands of general aviation airports that now need such service and allow for expansion of new airports based on the approval of a VLF non-precision approach.

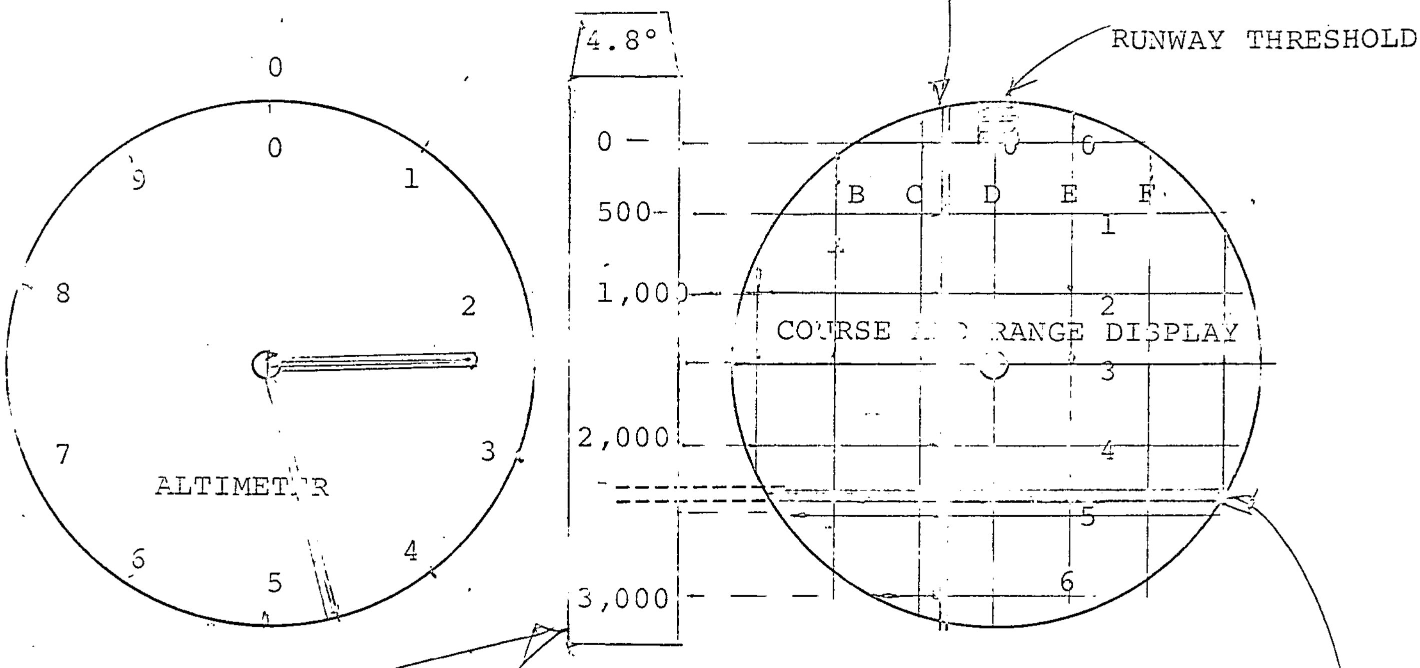
In many cases these small airports are already located in or near residential communities where noise from even light, single-engine aircraft must be considered an annoyance because of the generally low ambient noise level. Furthermore, if STOL or VSTOL is to be taken to "where the public is" at many locations away from the major airports (as many experts feel both aspects are essential to STOL or VSTOL's technical success and public acceptance); then a means for configuring noise abatement approaches to all runways at all airports must be considered. A generalized solution applicable to any and all cases must be sought and not a "customized" noise abatement procedure for each runway and each community that involves special electronic aids, such as localized ILS, VOR, VORTAC, etc., as these aids are far too costly for each airport to cover, for example, the four approaches to a cross-wind STOLport.

Typical steep angle approaches are in the range of about 4 degrees to about 14 degrees for STOL, general aviation, and helicopter aircraft. The following table gives various ratios of height vs distance in ratios such as 1:5, 1:10, 1:15, etc., and the corresponding glide path angle to the nearest tenth degree.

GLIDE SLOPE	DEGREES	GLIDE SLOPE	DEGREES	GLIDE SLOPE	DEGREES
1 : 22	2.6	1 : 16	3.6	1 : 10	5.7
1 : 20	2.9	1 : 15	3.8	1 : 9	6.3
1 : 19	3.0	1 : 14	4.1	1 : 8	7.1
1 : 18	3.2	1 : 13	4.4	1 : 7	8.1
1 : 17	3.4	1 : 12	4.8	1 : 6	9.4
		1 : 11	5.2	1 : 5	11.1
				1 : 4	14.0

The above table has the convenience that one can easily relate the height of the aircraft along the descent path using simple fractions. For example, on a 1:7 path or about 8.1-degree path, the aircraft is 1 NM high when 7 NM from the threshold. When the aircraft has then descended to a height of, say, 1,000 feet, then the aircraft is 7,000 feet from the threshold, and finally, when at, say, a 400/1 DA (decision altitude) condition, the aircraft is 7 X 400 or 2,800 feet from threshold. Furthermore, when examining the piloting aspects of steep angle approaches, past experience shows that much "selling" or convincing of pilots on the real merits and risks is essential. One matter of concern to pilots is the complexity of mentally computing angles, distances, heights, etc. A simple instrument as the one illustrated in Figure 5 would suffice as the table would be an adjustment the pilot makes when he selects the steepness of the angle. He does this based on his own ability, skills and the prevailing noise abatement requirements. This simplified, low-cost display illustrates the direct "raw" type data that can be utilized by the pilot of a slow aircraft, typical of general aviation. The pilot compares the barometric altimeter reading at 4 or 5 points while on the approach

THIS VERTICAL NEEDLE MOVES RIGHT AND LEFT
ACTIVATED BY THE AIRCRAFT POSITION RELATIVE
TO LOP'S SUCH AS B,C,D,E ETC.
IT RETAINS A MUTUALLY PERPENDICULAR RELATIONSHIP
WITH THE HORIZONTAL NEEDLE



THIS SCALE BETWEEN THE ALT. AND
COURSE AND RANGE DISPLAY
IS USED TO "CUE" THE PILOT

OF HIS ALTITUDE FOR THE

CHOSEN GLIDE PATH(1/12=4.8°)

TYPICALLY THE PILOT IS AT
ABOUT 2500 FT.

HE IS SLIGHTLY TO THE RIGHT
OF THE EXTENDED CENTERLINE

HE IS ABOUT 5 MILES FROM THRESHOLD

THIS HORIZONTAL NEEDLE MOVES
VERTICALLY SHOWING CHANGE IN
DISTANCE TO THE THRESHOLD OF
FIG____. IT IS POSITIONED BY

THE AIRCRAFT'S RELATIONSHIP WITH

LOP'S 1 thru 6. A DME TYPE INDICATION

BY TURNING THE KNOB OF THE SCALE
OTHER ANGLES ARE REPRESENTED(4.8 IS SHOWN)

LOW COST PILOT INSTRUMENTATION FOR NON PRECISION
APPROACHES USING VLF NAVIGATION COORDINATES.

according to the location of the VLF "distance to go" needle. These are admittedly old instrumentation techniques; one radio altimeter indicator has a scale that changes for different ranges that could be easily modified for such a display. Similarly, several DME indicators use meter movements that do the same thing.

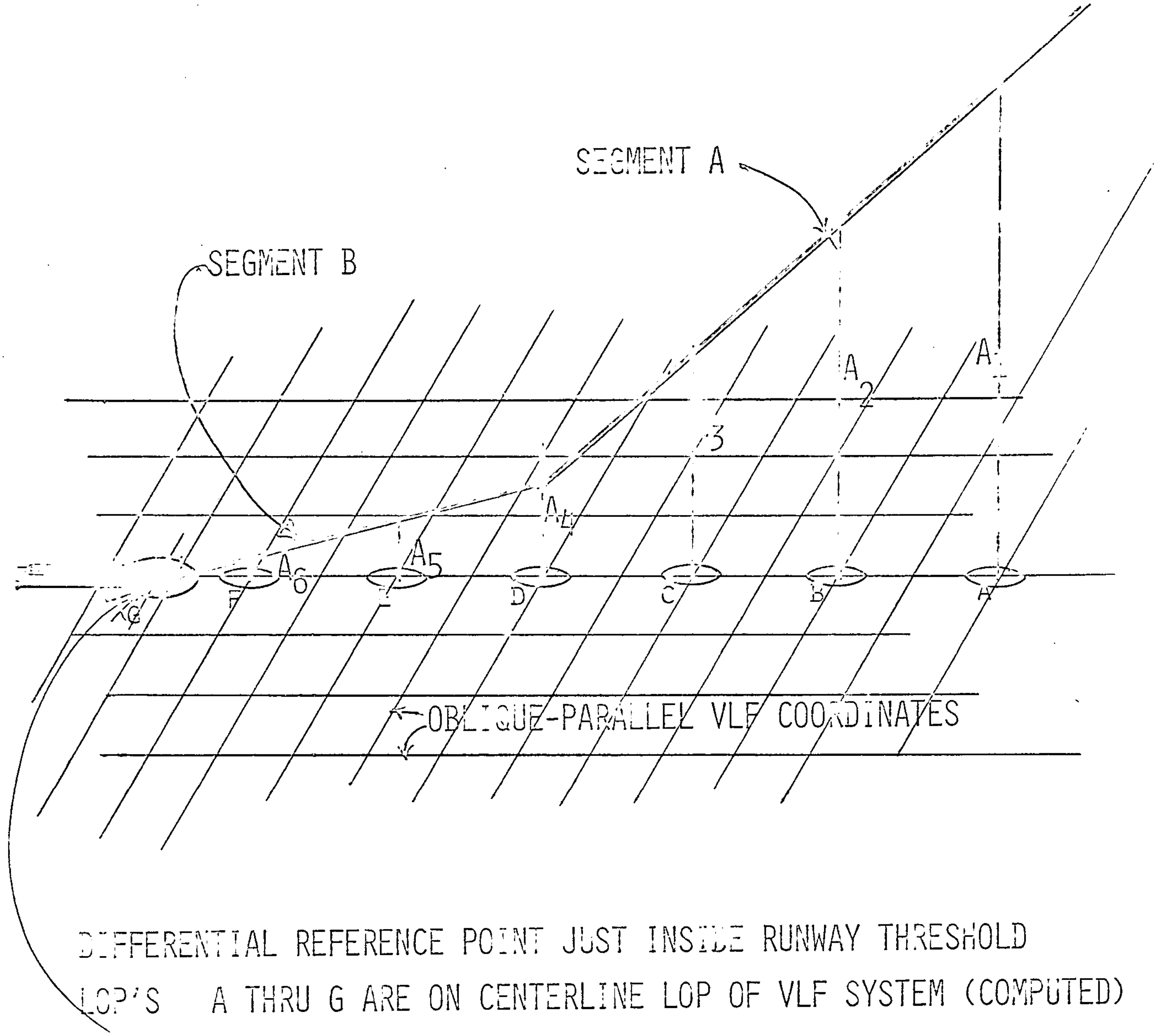
Thus, a small airport in its agreement with authorities to keep noise down and to prevent flying low over adjacent houses would operate perhaps at some angle typical, say, of a light aircraft of about 7 to 8 degrees. The important point is that this would be consistently adhered to at all times and, furthermore, would "visually train" the pilot who has only limited IFR experience so that each time he flew on this type of a steep angle display, he could judge his own ability. When he is IFR, flying non-visually to a decision altitude (DA) of, say, 400 feet, his first sight of the ground will not be a shock and he can be aware of the new visual cues to be expected.

MULTIPLE VS. SINGLE SEGMENT NOISE ABATEMENT APPROACH

The simple, single segment approach for general aviation ATC not only will prevent pilot errors in longitudinally estimating a track to the runway (such as localizer-"only" or VOR-leg "only"), but could be used in community noise control programs to assure the community that certain angles were being adhered to. This method of communicating with the opponents of aviation should prove helpful. Each of four approaches to a cross-wind runway airport could have a separate angle, dictated by the location of houses, obstructions, etc.; the point being that the lower angles are used on 1 or 2 approaches, and higher angles are used on the others, thus giving flexibility.

In the cases of STOL aircraft, we will expect larger aircraft initially, probably between the size of the McDonald Douglas 108 (French/Breguit STOL) and the DeHaviland Twin-Otter. The noise levels here and particularly in any jet-type (non-prop) STOL will require segmented approaches to (1) reduce noise considerably on the one hand, and (2) yet give the pilot of this larger aircraft a shallower angle near touchdown. Typically, segmented approaches might be a 7-degree path into a 3-degree path, the transition taking place above an altitude of 500/or 700 feet to assure the lower sink rate is reached well before any 200 or 300 foot altitude limit is reached. In this case the IF coordinates must be displayed with a modified scale for the STOL pilot. Here we deal with a more sophisticated pilot with IFR training and experience. More instrument cues will be needed and acceptable as well as more sophisticated flight instruments, perhaps even including a curved azimuthal approach prior to the segmented descent. Figure 6 illustrates a "segmented" noise abatement, VLF approach.

If STOL aircraft are to serve many small airports and draw the traffic from the major jetports, thus alleviating the many bottlenecks there, it is essential that this type of approach be possible to perhaps 400-1 NM or 300-¾ NM <u>wherever</u> STOL is needed without a separate ILS installation at each site. Most STOL service to be of public value must be able to operate in cross winds so that four approaches must be considered for regularity and safety of public service. Again, a wide-area navigation system, such as LF/VLF, can provide this capacity to the STOL service at low cost. All (4) approaches can be provided with segmented noise abatement guidance for perhaps 10 percent of the national cost of any other "400-1" solution to segmented approaches. When, say, 100-¼ visibility operation is justified (after traffic and public demand builds up for STOL), a separate costly ILS for one or



DIFFERENTIAL REFERENCE POINT JUST INSIDE RUNWAY THRESHOLD

LOP'S A THRU G ARE ON CENTERLINE LOP OF VLF SYSTEM (COMPUTED)

SPACE POSITION OF SEGMENT A DETERMINED BY COORDINATES OF ALTITUDE AND LOP($A-A_1$; $B-A_2$; $C - A_3$; ETC.)

SPACE POSTION OF SEGMENT B DETERMINED BY COORDINATES OF ALTITUDE AND LOP ($D-A_4$; $E-A_5$; $F-A_6$ AND $G-A_7$-TOUCHDOWN)

SEGMENTED STEEP ANGLE APPROACH FOR NOISE ABATEMENT USING VLF COORDINATES

FIG 6

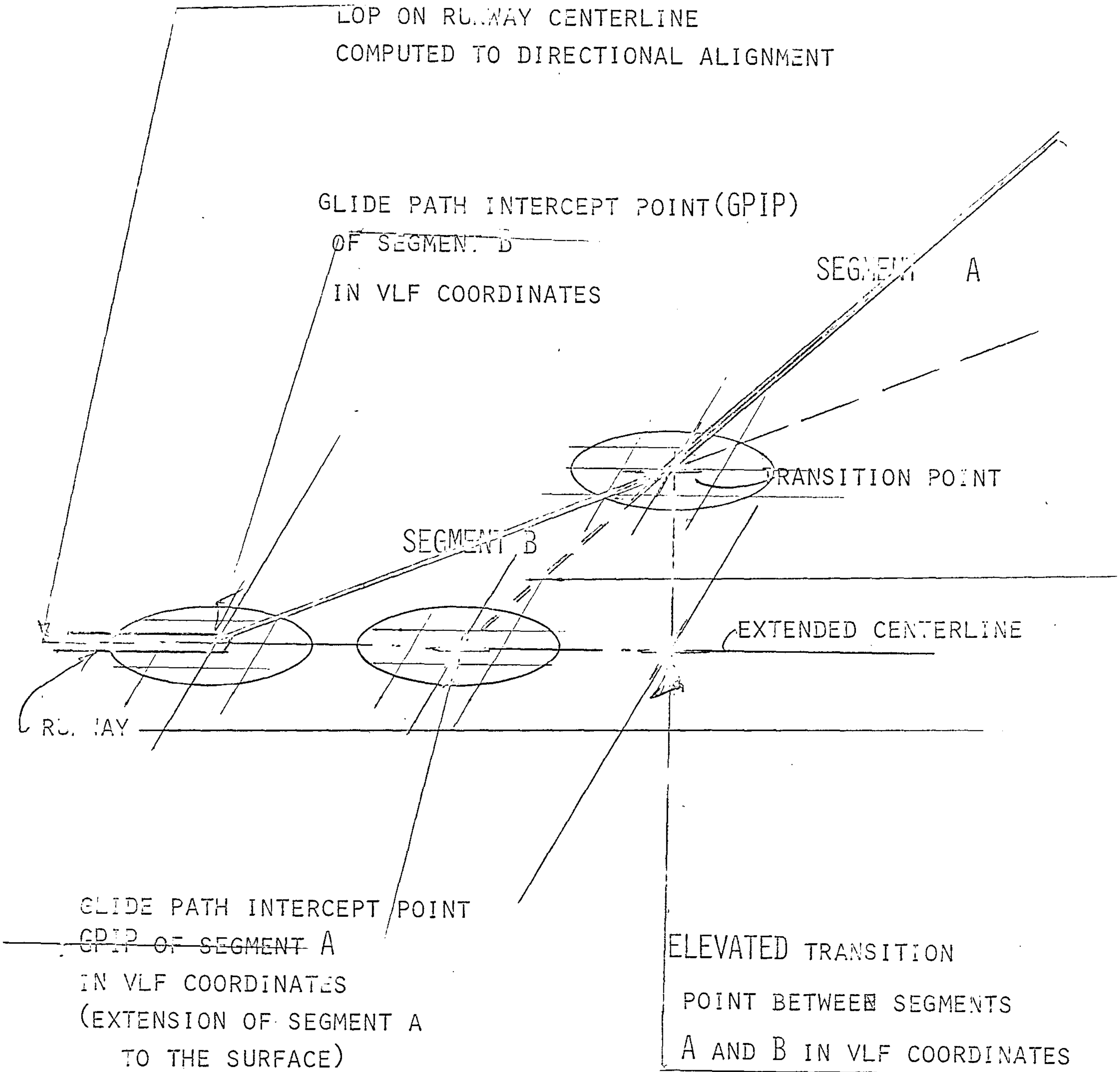
two approaches is then justifiable. Differential LF-VLF, with a steady state runway alignment and constant speed approach, should give about 1-2000 feet dispersion at the 400-foot decision altitude (DA), something equal to or better than a VOR approach or even an Area Nav (VOR-DME computer) approach where the average distance to the nearest VOR is considered (up to about 6 or 7 miles).

SEGMENTED STOL APPROACHES USING DUAL GPIP's AND LF/VLF COORDINATES

In order to finally specify a segmented approach in a quantitative manner using LF/VLF guidance coordinates (like Omega), it is best to consider two glide paths, each with a Glide Path Intercept Point (GPIP). This concept is illustrated in Figures 7 and 8. Depending upon the flight characteristics of the specific aircraft, steepness of angle, height over community, etc., glide path angle No. 1 is selected, as is its GPIP. This is the initial steep angle that, through the combination of added height and lower power settings, can provide from 12 to 18 db noise reduction, according to some experts. From several flight research programs at NASA, it has been learned where the steep path (say 6 degrees) should intersect the shallow path (No. 2) in height and distance from the touchdown. This data applies only to the specific aircraft tested and its applicability to a widely divergent spectrum of aircraft is unknown.

This is likely to vary considerably for different types of air vehicles, however, since we are independent of actual electronic units sited on the ground at specific points, such as GPIP No. 1 and GPIP No. 2, Figure 8 we are free to configure anything desired in the way of the geometrics of segmented approaches.

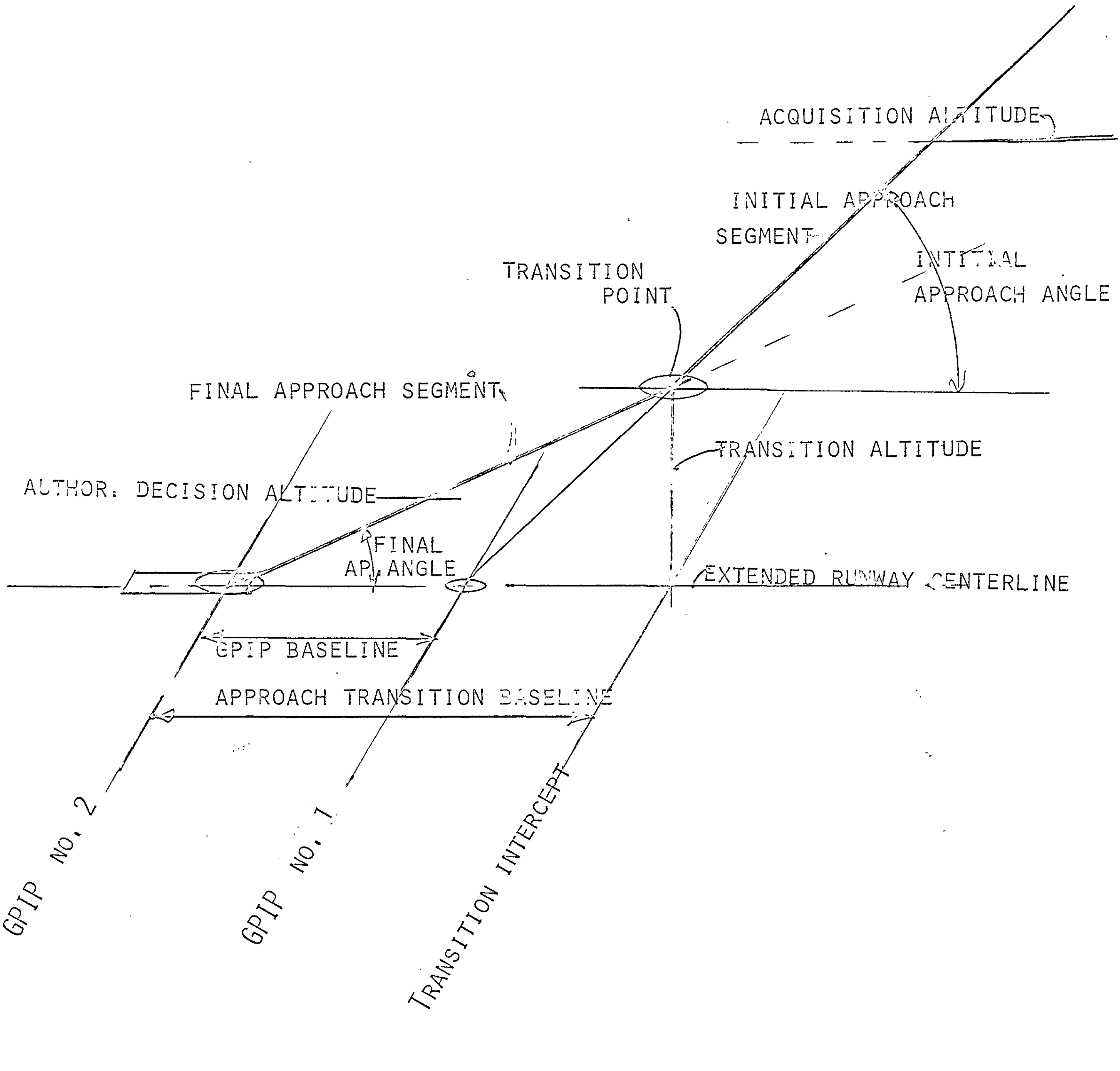
We can program into each type of aircraft its best GPIP-angle



USE OF GPIP AND ELEVATED TRANSITION POINT
IN "CONSTRUCTION" OF A VLF SEGMENTED APPROACH PROCEDURE

FIG 7

GLIDE PATH INTERCEPT POINT (GPIP)



DEFINITION OF TERMS USED IN SEGMENTED APPROACHES

FIG 8

data. Perhaps 4 or 5 "canned" approaches would be available to the pilot by push-button selection, any one program suitable to his specific aircraft. Where the obstructions, noise abatement needs, etc., might dictate, say, an 8-degree angle for vertical path No. 1 and a 4-degree angle for vertical path No. 2, this as a choice for that approach to that specific runway; a subsequent, less demanding location may allow, say, a 5-degree path transitioning into a 3-degree path for the next specific approach to a specific runway. The optimum 4 or 5 of such combinations would be pre-programmed and immediately available to the STOL pilot.

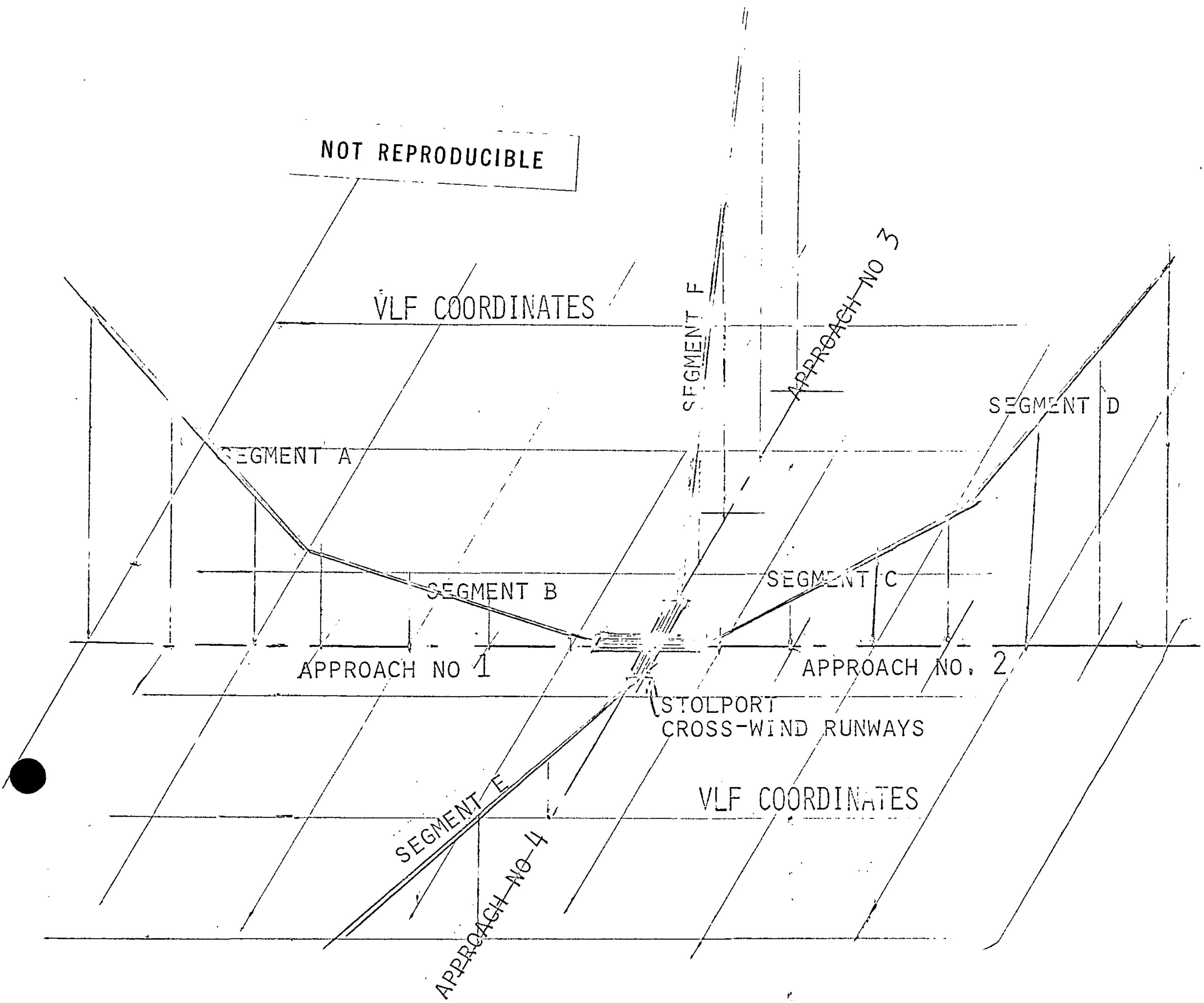
In the programming, the steep angle must be referenced to GPIP (No. 1) and the shallow angle referenced to (originating from) GPIP No. 2 (Figure 8). In essence two glide paths are considered separately in the selection of angle and GPIP origins; all coordinates are in terms of the two LOP's of the differential LF/VLF coordinates and altitude. However, the two vertical paths have an "intercept-point" in space that is also defined three-dimensionally in LF/VLF coordinates. (Figure 7) Since the surface VLF signals are the same as signals vertically above them, the VLF coordinates can be each established with a given altitude reference in the segmented approach concept.

Figure 8 defines some proposed terminology for the segmented approach. Although there may appear to be an infinite variety of combinations of the two angles, three longitudinal points, altitudes, etc., a specific aircraft will probably find a range of combinations suitable for most of its many landing environment factors (noise, obstacles, runway length, power, speed, displays, etc.).

However, taken as a whole national program for noise abatement, variations in aircraft types, approach speeds, noise criteria, etc., all possible combinations must be considered to accommodate the piloting and community objectives in each application of the segmented approach. Thus, one type of aircraft might be limited to three choices of segmented approaches; however, another aircraft, due to its differing flight characteristics, might have three different choices, yet each set of three approaches (six total) combine to meet the pilot-regulatory objectives. This flexibility of VLF is shown in Figure 9.

Again it is emphasized that if the community, FAA, and DOD can afford a "customized" steep-angle, segmented approach system for a runway, probably a microwave system derived from the national MLS program, then much lower ceilings could be authorized than "400-1" or "300-¾." However, due to the cost and technical limitations of current VHF-ILS, this system may not be widely applicable to noise abatement in the interim, nor would VHF-ILS be applied except to the most significant locations.

The VLF/LF segmented approach is a technical possibility that should be quickly examined and tested as the availability of VLF/LF signals at all STOLports and all general aviation airports is likely to occur well before the more sophisticated microwave landing system is extensively implemented. Omega is fully operational in 1975, offering this universal service. MLS is operational about 1980, with respect to widespread STOL installations even though limited installations may recur as early as 1977. In the future the two (VLF-Microwave) can be complementary; one providing say "CAT II" landing capacity to STOL service, and the other (VLF) a "400-1" or "300-¾" capacity to STOL. A given STOL route structure that may emphasize high density and low density areas (a typical operational goal of STOL) can readily use the combination of the two.



VLF COORDINATES PERMIT APPROACHES TO ALL RUNWAYS TO

TO BE ADAPTED TO THE CRITERIA FOR EACH APPROACH

FOR EXAMPLE , APPROACH SEGMENTS A THRU E MAY DIFFER IN ANGLE, GPIP,HEIGHT ABOVE OBSTRUCTIONS, AND TO FIT COMMUNITY NOISE-ABATEMENT PROCEDURES.

VLF COORDINATES PERMIT FLEXIBLE SEGMENTED APPROACHES TO ALL RUNWAYS OF AN AIRPORT

FIG 9

REFERENCES

1. Aviation Week, November 22, 1971 "Soviets Using Omegalike Navaid System."
2. "Application of VLF Navigation and Automatic Calibration of Barometric Altitude Sensing to General Aviation and a National Universal Coordinate System for the Guidance and Control of Air Traffic," final report, NASA Contract NAS 12-2071, December 1969.

3. "Study of Advanced Electronic Applications to Aeronautical Display and Control Problems," NASA Report CR-1240, January 1969.

4. "Aircraft Collision Avoidance Systems," Report of the Subcommittee of the Committee on Government Operations, House of Representatives, August 3, 1971 (also known as the "Brooks Committee" Report, an excellent review of the various problems, views, techniques, etc. of CAS are contained in this 384-page report).

5. Hearings Report of the "Moss Committee," U.S. Senate.

6. "Potential of Existing Avionics Technology," by S. Ratcliffe, Journal of the Institute of Navigation (British), Vol. 24, No. 4, October 1971.

7. "Altimetry," Appendix C-6 of Vol. 2, Report of DOT/ATC Advisory Committee (ATCAC), December 1969.

8. IEEE Transactions, AES-4, No. 2, March 1968. A group of papers on Collision Avoidance Systems and Problems.

9. "Omega Navaid Aviation Use Studies," Phil Klass, Aviation Week, November 29, 1971, Pp 38-41, inclusive.

10. "So You Want Corridors?" C. H. Ming (FAA Controller), Professional Pilot, July 1971.

11. "Anti-Collision Systems Fight Anticipated," Aviation Week, November 15, 1971.

12. "Approval of Area Navigation Systems for Use in the U. S. National Airspace Systems," AC 90-45, CHG-1, October 20, 1970. (Change to Basic Document AC 90-45 increasing authorized MDA's by 200 feet and visibilities by ½ mile, but not to exceed 2 miles until such time as VORTAC-R-NAV experience is gained.)